AEROSPACE REPORT NO.
TOR-2004(2172)-3231

Jupiter Icy Moon Orbiter
High Capability Instrument Feasibility Study
Executive Summary

4 February 2004

Prepared by

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Prepared for

NASA OFFICE OF SPACE SCIENCE
300 E Street SW
Washington, DC 20546

Contract No. FA8802-04-C-0001

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1.0 Introduction

This document serves to summarize the findings of the High Capability Instrument Feasibility Study conducted by The Aerospace Corporation. The term "high capability instruments" (HCI) refers to a class of instruments that can take advantage of large amounts of available power, and provide enhanced performance in sensitivity, spatial and spectral resolution, duty cycle, and data rate. The instruments described in this report were selected to potentially meet a high-priority subset of the overall preliminary science needs identified by the JIMO Science Definition Team. The instruments described herein are not to be considered representative of the actual JIMO Payload Suite, however.

The candidate instruments included for study include a visible and infrared imaging spectrometer, a thermal mapper, a laser altimeter, a multi-spectral laser surface reflection spectrometer, an interferometric synthetic aperture radar (InSAR), a polarimetric synthetic aperture radar (PSAR), a subsurface radar sounder, and a radio plasma sounder. In addition to a baseline design description for each instrument, a number of design options were explored in order to identify the overall trade space drivers. Instrument support resources, such as data management, telecom, thermal management, pointing stability, and protection from the natural and induced radiation environment, are documented in detail in the full report, and summarized here. Driving technologies for each instrument type were identified, as well as an estimate of the technology development and instrument development time. Information on heritage or legacy instruments similar to those considered here is also presented in the final report.

2.0 Study Objectives

The Aerospace Corporation study team was asked to address the following topics:

1. The instrument's trade space to assist in optimization of instrument performance, resource needs, and physical parameters.

2. The instrument's resource needs such as power, data rate, data storage, computational needs, and others.

3. The instrument's physical parameters, such as mass, volume, and others.

4. Technologies that need to be developed for the instrument to reach JIMO flight readiness.

5. Schedule estimates for instrument development.

6. The instrument's requirements such as pointing accuracy, duty cycles, fields of view, and others.

7. Datasets produced by the instrument (types, characteristics, size, and others as needed).

8. Effects of radiation and electromagnetic environment from Jupiter and the spacecraft on the design and performance of the instrument.

9. Critical instrument components requiring radiation hardening.

The list of instruments studied is shown in Table 2.1 below, together with the top-level measurement requirements.

Table 2.1: Top Level Instrument Requirements

Instrument	Requirements
Imaging Spectrometer	<100 m spatial resolution R = ~300 spectral resolution (higher spectral or spatial resolution would be even better) Visible (0.4-0.5 microns) and IR (1-5 microns) spectral range
Thermal Mapper	Spatial resolution of 100-300 meters Covers 5-1000 microns Low spectral resolution acceptable
Laser Spectrometer	Spectral resolution variable (some wavelengths more important than others) 5-10 micron spectral range
Laser Altimeter	10 m horizontal resolution 1 m vertical resolution
Radio Sounder	None
Radar Sounder	At depths from 2 to 30 km at 100 m vertical resolution At depths from 100 m to 2 km at 10 m vertical resolution
SAR / InSAR	10 m horizontal resolution

Other necessary functional requirements were derived internally, without interaction with the JIMO Science Definition Team or the external science and instrument community at the request of the customer. The study relied on prior experience with Earth-based remote sensing instruments, and some limited planetary instrument experience to derive additional needed information.

3.0 Instrument Summaries

Table 3.1 lists the primary accommodation parameters for the set of baseline instruments. The mass and power numbers listed in the table represent the total power required, which accounts for the need for multiple instruments, as in the the cases of the spectrometer and thermal mapper. The total mass and power numbers also account for that fraction attributable to thermal control and data handling provided by the spacecraft.

Tables 3.2-3.9 summarize the design and performance parameters for each of the baseline instruments. The mass and power numbers in these table reflect the instrument only and not spacecraft provided resources, and are therefore somewhat lower. These tables also summarize the required technology developments and development times. Table 3.10 summarizes the technology development items that enable the instrument set selected for this study.

Visible Imager/IR Imaging Spectrometer

Table 3.2 summarizes the visible imager/IR imaging spectrometer. The spectrometer consists of two identical instruments, each with a 14.8-degree field of view. This instrument is a push-broom imager that performs reflection spectroscopy and is only effective on the dayside of the body. In order to achieve two-fold coverage in 60 days, two instruments are needed to create an effective 30-degree swath. The visible imager senses 3 bands in the 0.4-0.5 micron range. The spectrometer senses 300 spectral bands in the 1-5 micron range. The total combined data rate is 42 Mbps (2 x 21 Mbps). Power requirements are very modest at 5 W average, and pointing is achievable with existing technology. These instruments are mounted to a scan platform, which can be used for pointing and to provide dynamic isolation from the spacecraft bus.

For the spectrometer, 300 spectral channels are achievable with existing technology and the instrument development time is a relatively short 46 months. In order to accommodate the higher spectral resolutions that are desired, the optical design could be simplified; a dispersive prism at the focus of the instrument could be replaced with a high density grating linear variable filter. To achieve a spectral resolution of 300 would require roughly 485 channels. Linear variable filters that could meet this need do not yet exist and are an area of technology investment and development. It is estimated that this technology would take on the order of 84 months to develop, assuming a funded development program.

Focal plane development and testing will be required to assure that suitable detectors are available for this mission. The high data rate associated with the large number of spectral channels is also a technology concern. The baseline instrument set generates approximately 4 times the anticipated available bandwidth in the JIMO time frame.

Thermal Mapper Instrument

Table 3.3 summarizes the thermal mapper instrument. The instrument is also configured for push-broom imaging from an altitude of 100 km. The sensor has a

5.5 deg cross-track field of view, which means that 3 sensors are needed to form the 15 deg swath width needed to achieve two-fold global coverage in 30 days. The optics for this instrument are also quite small, with a 2.45 cm aperture and 4.2 cm focal length. The imager consists of two detector arrays: a HgCdTe array similar to that used by the IR spectrometer for wavelengths shorter than 12.5 microns; and a microbolometer array for the longer wavelengths out to 100 microns. Instrument integration time of 167 msec is based on 1 pixel smear and the highest ground speed at Ganymede. A spectral resolution of 2 (center wavelength/bandwidth) with some overlap between bands results in 12 spectral bands across the desired spectral range of 8 to 100 microns. Mass and power are also modest. This instrument uses an integrated cryocooler to maintain temperature of the focal plane and cool the optics to 60 K. For the three shortest wavelengths, 62.5-micron pixels are summed 2 by 2 in order to achieve acceptable signal to noise. For the nine longer wavelengths, time delay integration across multiple rows of the microbolometer array is required to achieve acceptable signal to noise. The data rate for a single instrument is 72.8 kbps.

The instrument can probably be developed using existing technology. Cryocooler development or testing may be required, however. The point of reference for the cryocooler is the TRW advanced Mini Pulse Tube cryocooler. This unit was developed in 1995 and has no flight heritage. Development time is estimated at 53 months based on analogy to THEMIS (2001 Mars Odyssey) and TES (Mars Global Surveyor).

Laser Altimeter

Table 3.4 summarizes the laser altimeter. The instrument illuminates the surface with a 50 m spot beam that scans across a 15-degree swath. The system strives to achieve about 2000 collected 1-micron photons per emitted laser pulse. The resulting 800 signal electrons are based on performance of the linear mode Perkin Elmer 1-micron Si avalanche photo-diode. The 15-degree FOV requirement for the 100 km altitude case poses a considerable design constraint on the laser pulse rate and energy per pulse to achieve the contiguous 50-meter diameter sample spots on the surface.

The system is bistatic in design, similar to MOLA and ICESat. To achieve the high coverage rate, a scanning prism is used to deflect the laser beam to a spot on the icy moon's surface. Pointing knowledge is derived purely from diagnostics on the transmit beam. Because the receive telescope has a large FOV (15 deg and 5 deg for the 100 and 400 km cases, respectively), it is assumed that the measured spot will fall somewhere on a large detector array. The detector array does not provide any enhanced resolution since any 50 m diameter ground spot will be well within a single pixel. The array, therefore, only accommodates the optical constraints of the telescope design. This design results in a linear array about 1 mm by 10 mm at the detection plane where each of ten pixels would be equivalent to current flight hardened analog detectors.

The most challenging aspect of the laser altimeter was choosing the most optimum telescope and optical path to minimize full system mass and maximize science return. The off-axis telescope design accommodates the large 15-degree FOV but scales in mass quickly with aperture size. Consequently this forces a trade on laser power squared vs. aperture size for the telescope, in order to constrain mass growth.

The laser altimeter requires technology development in the areas of radiation compensated Nd:YAG laser, coordinated transmit and receive scanning, and active thermal control at higher altitudes to meet its design requirements. A radiation compensated Nd:YAG laser is currently at TRL 4 and would have to progress to TRL 5 before Phase B initiation. A recent study identified that the average time to progress from TRL 4 to TRL 5 is 1.5 years. Coordinated transmit and receive scanning capability is currently stated at TRL 3 which means it would take, on average, 2.9 years to develop the technology required to mature it to TRL 5. Detectors and processing algorithms must be developed and validated for the environment, also. Overall development time for the instrument is 53 months once these technologies reach TRL 5 based on analogy to MOLA and GLAS.

Multi-Spectral Selective Reflection Lidar (MSSRL)

Table 3.5 summarizes the multi-spectral selective reflection lidar (MSSRL), a laser reflection spectrometer. The general concept for the instrument is to transmit a number of discrete wavelengths, half of which will be on resonance for the above species and half that are off-resonance. A separate narrow line width laser emits each wavelength of interest. As in the case of the laser altimeter, all the wavelengths will be painted simultaneously on the moon's surface transverse to the ground track. A single but separate telescope, which is bore-sighted to the full FOV, will collect the reflected intensities. All of the transmitted wavelengths will be superposed into a single scanning footprint so that the sampling strategy will copy nearly identically that of the laser altimeter.

The instrument was conceived based on capabilities that are available in the industry but as such do not exist. As in the case of the laser altimeter, the MSSRL should undergo a 1-2 year architecture study and trade space examination. Preliminary tests should be conducted on materials of interest to clarify the true signal levels and show their consistency with the detection concept. A validation of the concept could be completed in 1-2 years using COTS technologies. The packaging of the laser bars and integrated micro-lenses are near TRL 5. A TRL 6 version of the transmitter could be ready 3 years after definition of the desired wavelengths. A detector concept would need to be defined early and built and tested, and one would also need to demonstrate optical compatibility with the dispersion specification of the receive prism. The detector and integration with a prism could be demonstrated in 2-3 years at TRL 6. The estimate for the instrument development time once the needed technologies reach TRL 6 is no less than 62 months, based on analogy to ALIAS, once technology development is complete.

Interferometric SAR

Table 3.6 summarizes the interferometric SAR. The InSAR is composed of two electronically steered antenna (ESA) pairs separated by a 5 m boom. Each antenna pair contains a receive-only (passive) antenna and a radar (active) antenna, for a total of four antennas. The transmit power is evenly split between each transmit/receive antenna pair. Each antenna beam will point between 20 and 45 degrees off nadir. The boom length (antenna separation) is 5 m.

The InSAR was designed to map two 30 km swaths; one is to the left and one is to the right of the ground track (nadir). The purpose of mapping two swaths on either side of the ground track is to mitigate the fact that the spacecraft altitude will not be known with sufficient accuracy to provide accurate absolute height. These swaths will provide global coverage of Europa twice in 30 days. The maximum usable swaths for the present design well exceed the required 30 km swath widths. The InSAR has the tightest pointing control and knowledge requirements of any of the instruments in the suite. The InSAR requires 1.7 and 6.6 kW power at 100 and 400 km, respectively. The raw data rate is above 2 Tbps, but it can be reduced to about 56 Mbps through processing before downlink.

Needed technology development centers on high-power, space-qualified Ka band transmitters, new processing algorithms for use on board the spacecraft, and a system to isolate the antennas from bus dynamics (vibration) that could reduce contrast. Transmitter technology is currently estimated at TRL 3-4, requiring approximately 3 years of development time, predominantly in the area of reducing mass and volume. On-board data processing algorithm development is also at the same level of maturity, although it is difficult to estimate the time required for new algorithm development. Vibration isolation is more mature, but existing approaches must be validated for this application. Instrument development time, once technology is mature, is greater than 76 months.

Polarimetric SAR

Table 3.7 summarizes the polarimetric SAR. This instrument uses a cylindrical reflector antenna, which will point between 20 and 45 degrees off nadir. The instrument requires 200 W average power at 100 km, and operates at a frequency of 3 GHz. Processed data rate is 36.737 Mbps. Pointing requirements are not overly stringent.

Further development of low mass/low volume/radiation tolerant radar electronics is desirable, but not necessary. The relatively high data rate for this instrument requires development of advanced data processing techniques, as with the InSAR.

Radar Sounder

Table 3.8 summarizes the radar sounder. The subsurface radar sounder utilizes two antennas: one is for higher frequency (above 10 MHz) operation and a second is for lower frequency (10 MHz and below) operation. The low frequency antenna is a 73.2 m dipole (optimized to 2 MHz). It will be employed by the radio sounder as well. The high frequency antenna is a 10 m Yagi antenna with three Yagi radiators of 3 m (optimized to 50 MHz). Both antennas will be oriented in the cross-track direction pointing directly nadir.

Both antennas are fed by a single transmitter, which transmits a maximum peak power of 1 kW at 100 km and 16 kW at 400 km. The transmitter operates with a 27% duty factor for 0.63 kW of average power at 100 km and 8.7 kW of average power at 400 km.

The radar sounder is designed to operate in a band spanning 3 MHz – 50 MHz (100 m – 6 m). There is a minimum of 5 frequencies available throughout this band for near simultaneous (interleaved) operation.

Space qualified transmitters in the bands and powers levels of the subsurface sounder have not been flown and will require development. Current technology is estimated at TRL 4, requiring 3 years to mature to TRL 5. Instrument development time is 39 months, once technology development is complete.

Radio Sounder

Table 3.9 summarizes the radio sounder. The radio sounder requires no new technology development. The device uses a 72 m dipole antenna and operates between 400 kHz and 2 MHz. The instrument generates 5.18 Mbps, raw and operates on 85 W power.

The antenna design for the JIMO application is a key issue. Because the ionospheres of the icy moons are believed to be more tenuous than the Earth's ionosphere, coverage at the higher frequencies used in the earlier designs is not required. This leads to a lower frequency instrument than previously designed and a longer dipole antenna.

Development time for this instrument is estimated at 34 months, and there are no technology developments identified for this instrument.

Key Technology Developments

Table 3.10 summarizes all the key technology developments that enable the instruments. As seen from the table, most of the enabling technologies have development times within 36 months, assuming a focused, funded development effort. A number of standouts include light-weight shielding, rad hard electronics and technology necessary to achieve spectral resolution of 300. Shielding is the largest system driver in terms of mass. The average shielding mass fraction is about 50% across the instruments, with the EO instruments being higher, and the radar instruments being lower. Light-weight shielding or, alternatively, 100 Mrad hard electronics, provide the most leverage, but are questionable within the JIMO development time frame. For the purposes of addressing feasibility of these instruments, conventional shielding was employed.

In some cases, instrument development times exceeded the time between the start of JIMO development (anticipated to be 2007) and the proposed 2012 launch date. Specific technologies, such as light weight shielding, high density linear variable filters, and rad hard electronics, may not be achievable within the JIMO development timeframe. Instruments development times exceeding the anticipated JIMO development time include the laser spectrometer, which is an entirely new instrument, the InSAR, and the polarimetric SAR. While functional InSARs and polarimetric SARs have flown on the shuttle, the pathway to transition of that application to the Jupiter environment is complex and drives the length of the instrument development effort. The length of the visible / IR imaging spectrometer development time is driven by the high spectral resolution of 300, and the consequent need for linear variable filter technology development. Reducing the capability of the spectrometer to 300 spectral channels allows development within the JIMO timeframe.

Table 3.1: Baseline Instrument Summary

	No. Units	Power		Mass		Data Rate			Data Handling		Thermal Control		
Instrument		Total Average (W)	Total Peak (W)	Total (kg)	% Shielding Mass	Total Raw (Mbps)	Total Processed (Mbps)	Duty Cycle	Storage Estimate (Gb)	Spacecraft Electronics Mass (kg)	Average Thermal Dissipation (W)	Spacecraft Radiator Area (m2)	Spacecraft Radiator Mass (kg)
Vis/IR Imaging Spectrometer	2	10	13	147	88%	42	42	50%	77	0.5	5	0.4	4
Thermal Mapper	3	151	152	107	58%	0.2	0.2	100%	1	0.8	76	24 kg cryocooler mass book-kept w/instrument total	
Laser Altimeter	1	1428	1428	76	13%	1	1	100%	4	1	1357	5	31
Laser Reflection Spectrometer	1	704	704	49	20%	1	1	100%	4	0.7	690	20 kg cryocooler mass book-kept w/ instrument total	
Interferometric SAR	1	1683	7923	337	36%	2332	56	100%	8563	8	337	1	8
Polarimetric SAR	1	204	1424	131	32%	150	37	100%	550	3	41	0.2	1
Subsurface Radar Sounder	1	2734	13454	131	37%	5	5	100%	19	3	547	2	12
Radio Plasma Sounder	1	87	172	81	60%	0.1	0.1	100%	0.5	1	17	0.1	1
Total	1	7001	25269	1060		2531	142		9218	19		9	57

Table 3.2: Baseline Vis/IR Imaging Spectrometer Performance Summary

Baseline Vis / IR Imaging Spectrometer Performance	Design Description	Rationale
Field of View	14.8 deg	Dayside Global Coverage in 30 days
Imaging Method	Push broom	Simple design
Optical Speed	2.7	Diffraction limited
Focal Length	27 mm	100 m GSD at 100 km
Aperture Size	10 mm	Maximize SNR at the diffraction limit
Cross Track Pixels	260	100 m ground sample distance (GSD)
Pixel Size	27 microns	1 pixel per GSD
Integration Time	52 msec	1 pixel smear at Ganymede
Spectral Channels	300	300 spectral channel baseline is achievable with current technology. Spectral resolution of 300, or 458 channels, requires technology development
Number of Sensors	2	Dayside imaging only, coarse estimate of two needed for two-fold global day side coverage
Sensor Mass	71 kg	100 km altitude
Sensor Power	5 W	100 km altitude
Sensor Data Rate	21 Mbps	300 In-scan channels, 14 Bits per channel
Pointing Stability	1.31 mrad/sec	Lowest ground speed at Europa
Technology Development	None for baseline, high density linear variable filters are needed for spectral resolution of 300.	
Estimated Technology Development Time	84 months	High density linear variable filters may require up to 7 years to develop for spectral resolution of 300.
Estimated Instrument Development Time	46 months	Analogy to MRO/CRISM, Cassini/VIMS

Table 3.3: Baseline Thermal Mapper Performance Summary

Baseline Thermal Mapper Performance	Design Description	Rationale
Field of View	5.5 deg	Two-fold global coverage in 30 days
Imaging Method	Push broom	Simplified design
Optical Speed	1.7	Diffraction limited
Focal Length	41.7 mm	300 m GSD at 100 km
Aperture Size	24.5 mm	Maximize SNR
Cross-track Pixels	29 & 32	Based on band
Pixel Size	62.5 & 125 microns	Based on band
Integration Time	167 msec	1 pixel smear at Ganymede
Spectral Channels	12	Center frequency limit for spectral resolution of 2
Number of Sensors	3	Two-fold global coverage in 30 days
Sensor Mass	36 kg	100 km altitude
Sensor Power	50 W	100 km altitude
Sensor Data Rate	72.8 kbps	12 channels, 10 bit system
Pointing Stability	1.31 mrad/sec	Slowest ground speed at Europa
Technology Development	None	
Estimated Technology Development Time	None	
Estimated Instrument Development Time	53 months	Analogy to MO/THEMIS and MGS/TES

Table 3.4: Baseline Laser Altimeter Performance Summary

Baseline Laser Altimeter Performance	Design Description	Rationale
Receive Telescope FOV	15	Two-fold global coverage in 30 days
Detection	Static Nadir Pointing Receive Telescope	Accomodates scanninng beam
Receive Telescope Optical Speed	2.67	
Focal Length	40 cm	300 m GSD at 100 km
Aperture Size	15 cm	Maximize SNR
Detector	Avalanche Photo Diode	2000 1 micron photons per pulse
Design	Bistatic	MOLA / GLAS
Scanning Approach	Multifaceted rotating prism	Beam Scan Rate
Laser	End-pumped slab design	High power, short pulse width, high pulse rates
Number of Sensors	1	Two-fold global coverage in 30 days
Sensor Mass	44 kg	100 km altitude
Sensor Power	1.4 kW	100 km altitude
Sensor Data Rate	1 Mbps	Estimate to obtain required measurement
Pointing Stability	0.183 mrad/sec	Slowest ground speed at Europa
Technology Development	Cooling, receive telescope, scanning prism, rad hard detectors	
Estimated Technology Development Time	36 months	Higher performance, rad hard detectors
Estimated Instrument Development Time	53 months	Analogy to MOLA, GLAS

Table 3.5: Baseline Laser Reflection Spectrometer Performance Summary

Baseline Laser Spectrometer Performance	Design Description	Rationale
Receive Telescope FOV	15	Two-fold global coverage in 30 days
Detection	Static Nadir Pointing Receive Telescope	Accommodates scanning beam
Receive Telescope Optical Speed	2.67	
Focal Length	40 cm	300 m GSD at 100 km
Aperture Size	15 cm	Maximize SNR
Detector	Dispersive Prism and HgCdTe Array	2000 1 micron photons per pulse
Design	Similar to Differential Absorption Lidar (DIAL)	
Scanning Approach	Multifaceted rotating prism	Bean Scan Rate
Laser	Diode laser stack with individually mounted lenses	Enables incoherent superposition of many laser diodes in the far field.
Number of Sensors	1	Two-fold global coverage in 30 days
Sensor Mass	49 kg	100 km altitude
Sensor Power	0.7 kW	100 km altitude
Sensor Data Rate	1 Mbps	Estimate to obtain required measurement
Pointing Stability	1.31 mrad/sec	Slowest ground speed at Europa
Technology Development	New development, transmit/receive coordination, receive dispersive prism	Components exist, instrument needs to be properly architected
Estimated Technology Development Time	36 months	Transmit/receive coordination
Estimated Instrument Development Time	>62 months	Analogy to ALIAS

Table 3.6: Baseline Interferometic SAR Performance Summary

Baseline Interferometric SAR Performance	Design Description	Rationale
Antenna	2 ESA	Interferometry
Duty Factor	0.2	Coverage, Pulse width
Frequency	35 GHz	JIMO Forum
Bandwidth	58 MHz	
Minimum PRF	2.776	
Swath Width	60 km	Typical Grazing Angles
Number of Sensors	1	Two-fold global coverage in 30 days
Sensor Mass	322 kg	100 km altitude
Sensor Average Power	1.7 kW	100 km altitude
Sensor Data Rate	55.9 Mbps	4 Bit BAQ
Pointing Stability	7.1 mrad/sec	Slowest ground speed at Europa
Technology Development	High power, space qualified Ka band transmitters, antenna jitter isolation, on-board data processing	
Estimated Technology Development Time	36 months	High power, space qualified Ka band transmitters
Estimated Instrument Development Time	> 76 months	Analogy to ERS-1, ERS-2, SRTM, ASAR

Table 3.7: Baseline Polarimetric SAR Performance Summary

Baseline Polarimetric SAR Performance	Design Description	Rationale
Antenna	Cylindrical Reflector	Polarimetry
Duty Factor	0.1	Coverage, Pulse width
Frequency	3 GHz	JIMO Forum
Bandwidth	52. 8 MHz	
Minimum PRF	0.893 kHz	
Swath Width	60 km	Typical Grazing Angles
Number of Sensors	1	Two-fold global coverage in 30 days
Sensor Mass	127 kg	100 km altitude
Sensor Average Power	200 W	100 km altitude
Sensor Data Rate	36.737 Mbps	4 Bit BAQ
Pointing Stability	2 mrad/sec	Slowest ground speed at Europa
Technology Development	High power, space qualified transmitters, on-board data processing	
Estimated Technology Development Time	36 months	High power, space qualified transmitters,
Estimated Instrument Development Time	> 81 months	Analogy to Envisat-ASAR, SIR-C

Table 3.8: Baseline Radar Sounder Performance Summary

Baseline Radar Sounder Performance	Design Description	Rationale
Antenna	10 m Yagi & 73 m Dipole	Yagi: > 10 MHz, Dipole < = 10 MHz
Duty Factor	0.27	Coverage, Pulse width
Frequency	3, 5 10, 30, 40, 50 MHz	Multiple interleaved frequencies, uncertainty in subsurface properties
Pulse Length	300 microseconds	
PRF	150 Hz	
Number of Sensors	1	Two-fold global coverage in 30 days
Sensor Mass	117 kg	100 km altitude
Sensor Average Power	2.7 kW	100 km altitude
Sensor Data Rate	5.18 Mbps	
Sensor Pointing Stability	None	Very large beamwidth
Technology Development	High power, space qualified transmitters	
Estimated Technology Development Time	36 months	High power, space qualified transmitters
Estimated Instrument Development Time	39 Months	Analogy to MARSIS, SHARAD

Table 3.9: Baseline Radio Sounder Performance Summary

Baseline Radio Sounder Performance	Design Description	Rationale
Antenna	72 m Dipole	Yagi: > 10 MHz, Dipole < = 10 MHz
Duty Factor	0.27	Coverage, Pulse width
Frequency	400 kHz - 2 MHz Sweep	Uncertainties in Jovian moon ionospheres
Pulse Length	300 microseconds	
PRF	150 Hz	
Number of Sensors	1	Two-fold global coverage in 30 days
Sensor Mass	79 kg	100 km altitude
Sensor Average Power	85 W	100 km altitude
Sensor Data Rate	0.13 Mbps	
Pointing Stability	Coarse	Very large beamwidth
Technology Development	None	
Estimated Technology Development Time	None	
Estimated Instrument Development Time	34 months	Analogy to Alouette 1, Alouette 2, ISIS 1, ISIS B

Table 3.10: Key Technology Developments

		Instrument Enabled								Instrument Subsystem Enabled									
Technology Development	Time to TRL 5 (Months)	VIS/IR Spectrometer	Thermal Mapper	Laser Altimeter	Laser Spectrometer	InSAR	Polarimetric SAR	Radar Sounder	Radio Sounder	Instrument Processing Electronics	Instrument Power Electronics	Instrument FPAs, Detectors, Emmiters	Instrument C&DH	Instrument Thermal Control	Instrument ADCS	Instrument Structure	Instrument Data Rate	Instrument Shielding	Comments
Light Weight Radiation Shielding	UNK	x	x	x	x	x	x	x	x									x	Possible 2007 time frame
High Performance Rad Hard Electronics	UNK	x	x	x	x	x	x	x	x		x		x		x		x	x	SiC a candidate in 2007 time frame
Lightweight Active Cooling	36	x	x	x										x					
High Density Linear Variable Filter	84	x																	Necessary to achieve spectral resolution of 300.
Rad Compensated Nd:YAG Lasers	24				x														
Receive Telescope Design	24			x	x							x							
Beam Transmit and Receive Coordination	24			x	x														
Rad Hard Detector Arrays	24	x	x	x	x					x		x							
Scanning Prisms	36			x	x							x							
Dispersive Prisms	36				x							x							
Space Qualified High Power Ka Band Transmitters	36					x	x	x		x	x						x		
Space Qualified Processors 1 GFLOP	36					x	x	x		x							x		
Rad Hard Dielectric Structures	UNK	x	x	x	x											x			Likely in 2007 time frame
Antenna Jitter Isolation	36					x	x									x			
Data processing algorithms	36	x		x		x	x	x									x		
Diode Laser Bars With Integrated Microlenses	24			x								x							

4.0 High Capability Payload Resource Considerations

The baseline instrument suite assumes the use of shared resources in order to accommodate common instrument needs such as pointing and control, power conversion, processing, distribution and shielding, data storage, telecommunication, and thermal management. This section summarizes each of these resources.

Scan Platform

A scan platform is employed to point the electro-optical instruments (Vis/IR spectrometer, thermal mapper, laser spectrometer, etc.) and isolate them from the dynamics of the rest of the spacecraft. The scan platform consists of an instrument accommodation platform, bi-axial drive system, independent attitude reference and control system, and attitude sensing devices such as star cameras and sun sensors. It is assumed that additional instruments not included in this study will be accommodated on the platform, such as wide-, medium-, and narrow-angle cameras. Notional mass of the scan platform with representative instrument accommodation is provided in Table 4.1.

Table 4.1: Scan Platform Mass Breakdown

Component	*Mass (kg)*
Narrow Angle Camera	20
Medium Angle Camera	5
Wide Angle Camera	3
IR Spectrometer	71.1
Thermal Mapper	36.2
Digital Sun Sensors	14.8
Gyros	54.8
Star Camera Assembly	56.6
Integration Hardware/Bracketry	13.1
Wire Harness	13.7
Platform Mass	78.5
Actuator Mass	26.9
Total Mass of EO Platform	**393.6**

Pointing Requirements

Table 4.2 summarizes zero-to-peak pointing knowledge, control, and stability requirements for the baseline instrument concepts. The tightest pointing control and knowledge requirements are for the inteferometric synthetic aperture radar (InSAR), while the tightest pointing stability requirements are for the laser altimeter. Since some of the instruments are potentially fixed to the bus, there are implications for what the bus must provide in terms of pointing and jitter control. The InSAR control and knowledge requirements would not be difficult to meet for a typical Earth-orbiting spacecraft, but they may be difficult to meet while operating in the high radiation environment around Jupiter. The laser pointing stability requirements would also not be difficult to meet for a smaller bus, but they may be a challenge for JIMO because of its very large and flexible structure.

Table 4.2: 3-Sigma Pointing Requirements for Baseline Instruments

	Pointing Control (mrad)			Pointing Knowledge (mrad)			Pointing Stability (mrad/sec)		
	roll	pitch	yaw	roll	pitch	yaw	roll	pitch	yaw
IR Spectrometer/Visible Imager	13	13	39	6.5	6.5	19.5	1.31	1.31	3.93
Thermal Mapper	13	13	39	6.5	6.5	19.5	1.31	1.31	3.93
Interferometric SAR	52	0.8	0.8	17.5	0.4	0.4	100	7.1	7.1
Polarimetric SAR	140	3.34	3.34	47	1.67	1.67	78	2	2
Radar Sounder	123	123	NA	62	62	NA	NA	NA	NA
Radio Sounder	123	123	NA	62	62	NA	NA	NA	NA
Laser Altimeter	13	13	39	2	2	6	0.183	0.183	0.549
Laser Spectrometer	13	13	39	6.5	6.5	19.5	1.31	1.31	3.93

In addition to the requirements listed above, there is an issue regarding the effects of vibration on InSAR measurement quality. Translational vibration of an InSAR antenna in the direction of its boresight would lead to phase modulation that tends to increase the level of side lobes in SAR imagery. This has the effect of decreasing image contrast. The vibration amplitude should be limited to maintain good image quality. Since this is a relatively small value for a structure as large and flexible as JIMO, it may require vibration isolation of the InSAR and/or other measures to mitigate the effects of vibration.

Power Conversion, Processing, Distribution and Shielding

The present state of the art for total dose in power electronic devices is approximately 1MRad for power MOSFETs, 300kRad for Shottky and ultra fast rectifiers, 200kRad for low-dropout linear voltage regulators, and 1MRad for small, standalone modular converters. Pulse-width modulator controllers and MOSFET drivers are hard to 200-300kRad.

Passive components (inductors, transformers, capacitors) are relatively immune to ionizing radiation and displacement damage. Switching components control the flow of electrical energy into and out of the inductors and transformers. Modern switching components are among the most radiation-hardened of solid-state components. The radiation hardness of control circuits depends on the underlying solid-state technologies and device geometries employed. Using bipolar transistor technology or large-geometry CMOS instead of newer, small geometry technologies gives the best radiation performance for the control circuitry.

Silicon Carbide

High-band gap materials such as silicon carbide (SiC) would result in better radiation displacement damage tolerance, as well as high-temperature operation. SiC devices have been under development for many years. Presently, there are commercial Shottky diodes and high-temperature sensors being made using SiC. It is reasonable to assume that the next few years will bring improvements in yield and more reliable devices for power electronics, including power MOSFETs with total dose hardness in excess of 100MRad, but it is not certain that the technology will mature in time for incorporation into the JIMO design.

Wire Insulation

Wire insulation exists that can withstand 1000 Mrad. Teflon is commonly used as a jacket for shield-twisted pair wire, coaxial cable dielectric, and as an adhesive and outer and inner layer in Kapton-insulated wiring. It has been shown that wrapped insulation withstands less radiation than extruded insulation, and that radiation degrades flex life, and that FEP extruded form of Teflon had a longer radiation life than the tape form, a longer life than PTFE, and has tested it to180 MRad. Kapton is less flexible, less fuel compatible, hydroscopic, more susceptible to arc-tracking, and can burn in a vacuum forming a conductive carbon-like material. This means a short can spread from one wire to many wires in a wire bundle. In the worse case, the entire wire harness can burn causing extensive thermal damage to surrounding hardware.

Advanced Shielding for High Radiation Environments

Investigations of tri-layer radiation shielding suggests that mass thickness efficiency can be improved by 30-50% by using a very dense material such as Tungsten (W) or Tantalum (Ta) in combination with Aluminum. Improving mass thickness efficiency of 0-25% implies that shielding to 100 krad would require approximately 5.8-7.7 mm of W or 6.7-8.9 mm of Ta. In addition, savings can be achieved by increasing the packing density of instruments and electronics, when possible. Increasing the packing density of electronics can lead to more stringent requirements on the thermal system. Mass savings can also be accomplished by the strategic placement and integration of components to take advantage of shielding from other components and structure from the spacecraft bus.

On Board Storage

Technologies available for space-certified, on-board data storage range from mechanical and magnetic to solid state. Mechanical and magnetic technology consists primarily of reel-to-reel magnetic tape transports. This technology has a long history of successful space operation. Solid state technology is primarily solid-state digital recorders (SSDR). While this is a newer technology, SSDRs have a decade long space legacy.

Rotating disk storage devices possess greater storage capacity than SSDRs and may have potential space application for JIMO. Non-contact bearings that use magnetic fields to separate the two metallic interfaces may greatly increase the life of these devices. There are currently no space-qualified non-contact bearing rotating disk products available. All current spacecraft rotating bearing requirements are being met with conventional lubricated bearings, which are commonly used in gyros and reaction wheels, and have achieved long life and reliability based on legacy evolved designs.

Telecommunications

Three alternatives to increase the possible telecommunication downlink data rate are discussed in the full report. The first method employs a 3-meter or 5-meter antenna on the JIMO spacecraft operating at 35 GHz to transmit data via the 70m DSN antennas. The second method utilizes multiple lasers on board JIMO operating in the THz band with an optical relay orbiting Earth. The third method is to use an RF relay satellite in high orbit around Jupiter or possibly in a Heliocentric, Jupiter trailing or leading orbit.

Instrument Thermal Management

Thermal management resources include heat pipes, radiator area and active cooling systems to maintain instrument thermal balance. The laser instruments require a significant amount of radiator area, if cooled passively, the radar instruments do not use active cooling and can be managed thermally using heat pipes and radiators. In the proposed instrument architecture, the thermal management is accomplished by a single parasitic radiator sized to accommodate the passively controlled instruments.

Table 4.3 presents options for meeting the thermal requirements of the visible/IR imaging spectrometer. The thermal control summary for the thermal mapper is presented in Table 4.4. Table 4.5 presents the thermal control resources required for the instruments that use parasitic a radiator. Note that the laser spectrometer uses active cooling for the laser, similar to the thermal mapper. However, operating temperatures have not been determined for this device and insufficient detail exists at this time to provide further thermal design detail for the active cooler. For the purposes of comparison, the laser spectrometer using passive thermal control is presented in Table 4.5.

Table 4.3: Vis/IR Imaging Spectrometer Thermal Resource Requirements

Vis/IR Imaging Spectrometer	Temperature Requirement (K)	Cooling Required (mW)	Power Required (W)	Number of Heat Pipes	Radiator Area (m 2)	Total Mass (kg)
Option 1 Environmentally Shielded Radiator	105	100 per Instrument	N/A	1	0.1	1 to 2
Option 2 Pulse Tube Cryocooler	105	100 per Instrument	11 to 14	N/A	N/A	3 to 5

Table 4.4: Thermal Mapper Thermal Resource Requirements

Thermal Mapper	Temperature Requirement (K)	Cooling Required (mW)	Power Required (W)	Number of Heat Pipes	Radiator Area (m 2)	Total Mass (kg)
Pulse tube cryocooler cooling enclosure housing FPAs	60	2.4 per Instrument	32 to 45	N/A	N/A	8 to 14

Table 4.5: High Power Instrument Passive Thermal Resource Requirements

	Assumed Ave Power Dissipation (W)	Efficiency	Number of Heat Pipes	Radiator Area (m 2)	Radiator Mass (kg)	Total Mass (kg)
Laser Altimeter, 100 km	1350	5%	12	5	27	31
Laser Spectrometer, 100 km	690	2%	6	2.5	14	16
Interferometric SAR, 100 km	340	80%	3	1.2	7	8
Polarimetric SAR, 100 km	40	80%	1	0.2	0.8	1
Subsurface Radar Sounder, 100 km	550	80%	5	2	11	12
Radio Plasma Sounder, 100 km	18	80%	1	0.1	0.4	1
Total at 100 km	2988		28	11	60	69